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Author: Ewa Wójcik, Magdalena Zielińska, Ryszard Chybiorz, Jerzy Żaba

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Depositional architecture of marginal multiple-source ramp of the Magura Basin (Eocene Flysch formation, Outer Western Carpathians)

EWA WÓJCIK✉, MAGDALENA ZIELIŃSKA, RYSZARD CHYBIORZ and JERZY ŻABA

Faculty of Earth Sciences, University of Silesia in Katowice, Będzińska St. 60, Sosnowiec 41-200, Poland; ✉ewa.wojcik@us.edu.pl

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Abstract: The Zembrzyce Beds were studied to interpret the environments and facies in the western part of the Siary Subunit. New sedimentological data were obtained for the reconstruction of the depositional architecture of the Zembrzyce Beds. Based on detailed facies analysis, 9 facies and 4 facies associations were recognized. The facies associations represent different architectural elements of a submarine fan, such as: termination of distributary channel with transition to depositional lobe (distal part of mid-fan/outer fan sub-deposystem), lobes and distal lobes (outer fan sub-deposystem). According to the classification of Reading & Richards (1994) the fan deposystem can be classified as mud/sand-rich ramp. This system consists of several elongated lobes that formed synchronously, migrated laterally, and then retreated or decayed. The depositional system was supplied from the north and north-east. The inner-fan sub-deposystem was not detected. The sediments were deposited by high- and low-density turbidity currents and hyper-concentrated density flows sensu Mulder & Alexander (2001) with participation of the depositional background processes (pelagic settling). The sedimentary conditions of the Zembrzyce Beds during the Late Eocene were controlled by tectonic movements, the progress of the subduction and the global sea level changes.

Keywords: Outer Carpathians, Siary Subunit, Zembrzyce Beds, depositional architectural elements, Eocene, turbidites.

Introduction

The Zembrzyce Beds occurring in the Magura Unit are typical member of the Siary Subunit. In the Polish part of the Magura Unit, the Zembrzyce Beds outcrop in many localities and were described by: Książkiewicz 1935, 1970, 1974; Burtan et al. 1959; Golonka & Wójcik 1978a, b; Oszczypko & Wójcik 1989; Ryłko et al. 1992; Paul 1993; Wójcik & Rączkowski 1994; Oszczypko-Clowes 2001; Chodyń 2002; Leszczyński & Malata 2002; Gdel & Leszczyński 2005; Cieszkowski et al. 2006; Kopciowski 2007, 2014, 2015; Warchoł 2007; Ryłko & Paul 2013; Jankowski & Kopciowski 2014; Kopciowski et al. 2014a, b; Nescieruk & Wójcik 2014.

The Zembrzyce Beds (Middle–Late Eocene), also known as the Zembrzyce Shale Member (Cieszkowski et al. 2006; Golonka & Waśkowska-Oliwa 2007; Golonka & Waśkowska 2011), consist mostly of massive, marly shales (seldom clayey shales), mudstones, and marls interbedded by glauconitic sandstones. The thickness of the Zembrzyce Beds is up to 500 metres (Cieszkowski et al. 2006; Golonka & Waśkowska-Oliwa 2007). In literature the Zembrzyce Beds are also called as the Sub-Magura Beds (Paul 1980, 1993; Oszczypko et al. 1999; Chodyń 2002; Oszczypko-Clowes 2001; Ryłko & Paul 2013; Jankowski & Kopciowski 2014; Kopciowski et al. 2014a, b) and this term is used in older publications. What is more, sedimentological research carried out by various authors including Golonka & Wójcik 1978a, b; Golonka 1981; Cieszkowski et. al. 1985, 2006; Oszczypko et al. 2005 in the area of the Siary Subunit identified its lithological discrepancy between the western and eastern part. Initially 3 separate lithostratigraphic units were distinguished: the Sub-Magura Beds (Książkiewicz 1935), Magura Sandstones (Paul 1868) or Magura Beds (Książkiewicz 1966) and Supra-Magura Beds (Książkiewicz 1966) in the western part. Next Książkiewicz (1974) included all these 3 units in the Magura Beds and proposed to change the name: Sub-Magura Beds into the Zembrzyce Shales and Supra-Magura Beds to Budzów Shales. In the eastern part of the Siary Subunit, all these sediments were classified as Magura Beds (Leszczyński & Malata 2002). Koszarski & Koszarski (1985) applied the name of Wątkowa Sandstones for the Magura Sandstones, and Bromowicz (1992) for the shaly upper part of the Magura Beds applied the name of Małastów Shales in the eastern part of the Siary zone. What is more, Oszczypko et al. (1999), Oszczypko-Clowes (1999, 2000, 2001) and Malata (2001) mentioned the units included by Książkiewicz (1974) to the Magura Beds as the Zembrzyce Beds, the Wątkowa Sandstones and the Budzów Beds respectively. Consequently, the designation of the Zembrzyce Beds is currently used because of the presence of greyish-green shales for which the stratotype profile is located near Zembrzyce village.

Opinions and information on the depositional system that produced the Zembrzyce Beds are still inconsistent and incomprehensive. Leszczyński & Malata (2002) interpret the Magura Beds as a ramp deposit that gradually developed towards the SE and E along the base of the basin slope.

Kopciowski (2007) in the eastern part of the Siary Subunit attributes the Zembrzyce Beds to a point source, mud-rich submarine fan, which is a continuation of hemipelagic variegated shales sedimentation, but above the calcite compensation depth (CCD) zone. Warchoł (2007) in the same area, describes the Magura Beds as a system of linearly supplied ramps. The author also suggests not to divide the Magura Beds into Zembrzyce Shales (Szymbark Shales), Wątkowa Sandstones and Budzów Shales (Małastów Shales), and the existing tripartite division should be to apply only in exceptional cases.

The common feature of the theories about the deposition of the Zembrzyce Beds is that these sediments were deposited by different mass gravity transport processes and indicate sedimentation in a deep-marine environment.

Up to now research on the Zembrzyce Beds was concerned primarily with lithology, stratigraphy and tectonics. The lack of comprehensive sedimentological research on the Zembrzyce Beds and the ambiguity about the Zembrzyce Beds depositional system have become the basis for analysis of the facies and depositional architecture of the Zembrzyce Beds.

This paper presents a depositional model for the Zembrzyce Beds in the marginal part of the Magura Unit (the Siary Subunit). Developing the model required the lithological analysis of the Zembrzyce Beds, bed by bed, and the reconstruction of the sedimentary basin. The sedimentary material of the Zembrzyce Beds and the geological history of the Magura sedimentary basin were the main subjects of the study. Sediment properties, such as lithology, sedimentary structures and textures, were used to recognize the sedimentation processes. Palaeotransport measurements were used to determine the direction of currents transporting clastic material within the Magura Basin (the Siary Subunit) and to reconstruct the source areas for the Zembrzyce Beds. Modelling the elements of the depositional architecture of the Zembrzyce Beds depended on correlating the lithological features of the sediments with the deposition mechanisms, palaeotransport directions and stratigraphy.

The study area is located in the western segment of the Siary Subunit, to the south of Żywiec, in Jeleśnia village (Fig. 1).

Geological background

The Outer Western Carpathians are composed of sediments of marine origin. These are mainly alternating sediments of conglomerates, sandstones, mudstones, and claystones, with subordinate beds of marls and limestones, which were folded in the Palaeogene and Neogene and overthrust as nappes to the north. The Outer Carpathians are made up of a stack of nappes and thrust sheets showing different lithostratigraphy and tectonic structures. Generally each Outer Carpathian nappe represented separate or partly separate sedimentary subbasins (e.g., Oszczypko & Ślączka 1985; Nemčok et al. 1989, 2001; Vašíček et al. 1994; Golonka & Krobicki 2001; Golonka 2004; Ślączka et al. 2006; Golonka et al. 2008; Kováč et al. 2017). Within the Outer Carpathian sedimentary basin, there were ridges, which recorded periods of sinking and uplifting corresponding to the tectono-stratigraphic stages of the Carpathians orogenic regime. Ridges formed the primary source of clastic material for the Outer Carpathian depositional system, and in the inversion phases, the ridges divided the Outer Carpathian basin into a number of sub-basins (e.g., Oszczypko 1999, 2004). The Zembrzyce Beds were deposited in the Siary Subunit (northernmost subunit of the Magura Unit), and the source of the clastic material was the Silesian Cordillera, situated to the north (Leszczyński & Malata 2002; Oszczypko et al. 2006; Kopciowski 2007; Warchoł 2007).

The Magura Unit is the largest and the southernmost tectonic unit in the Outer Carpathians. Within the Magura Unit, the subunits were distinguished based on the differences in sediments and facies succession. Starting from the south, the subunits are as follows: the Krynica Subunit, the Bystrica Subunit, the Rača Subunit, and the Siary Subunit (e.g., Książkiewicz 1958; Świdziński 1958; Sikora 1970; Oszczypko 1973; Koszarski et al. 1974; Żelaźniewicz et al. 2011) (Fig. 1B). However, it must be emphasized that the boundaries between the subunits are tectonic (faults, overthrusts) and that they have not been precisely located and defined throughout the full extent of the Magura Unit (Oszczypko 1973; Książkiewicz 1977).

Siary Subunit lithostratigraphy

The Siary Subunit consists mostly of Palaeogene sediments with subordinate Cretaceous deposits (Fig. 1C,D). In the area of the Polish Outer Carpathians, the Siary Subunit reveals its facial differentiation between the eastern and western parts with the border at the Dunajec river. The eastern part's profile is dominated by thick-bedded glauconite Magura sandstones — Wątkowa Member, and the equivalent of the Zembrzyce Beds are the Szymbark Beds (Kopciowski 1996, 2007; Leszczński & Malata 2002; Leszczyński et al. 2008; Warchoł 2007). The marly shales and cross-bedded sandstones belonging to the upper part of Magura Beds was called by Bromowicz (1992) the Małastów Shales and they are the equivalent of the Budzów Beds characteristic of the western part of the Siary Subunit. In the western part the Zembrzyce Beds and Budzów Beds predominate, interbedded by the glauconite Magura sandstones (Cieszkowski et al. 2006; Warchoł 2007). Further west, in the territory of Slovakia, the Outer Rača Subunit is a synonym of Siary Subunit and the equivalent of Zembrzyce, Magura and Budzów Beds is the Zlín Formation (Middle/Late Eocene) (Cieszkowski et al. 2006; Teťák 2010; Teťák et al. 2016). Glauconitic sandstones are typical for the Vsetín Member (Zlín Formation). Intercalations of glauconitic sandstones and greywacke Magura type sandstones are typical for the Babiše Member (Zlín Formation) (Teťák 2010).

The typical Siary Subunit's lithostratigraphic succession in the study area starts with the Ropianka Formation (Senonian/Palaeocene) (Fig. 1D), with medium and thin beds of fine-grained calcareous sandstones. The sandstones are overlain by

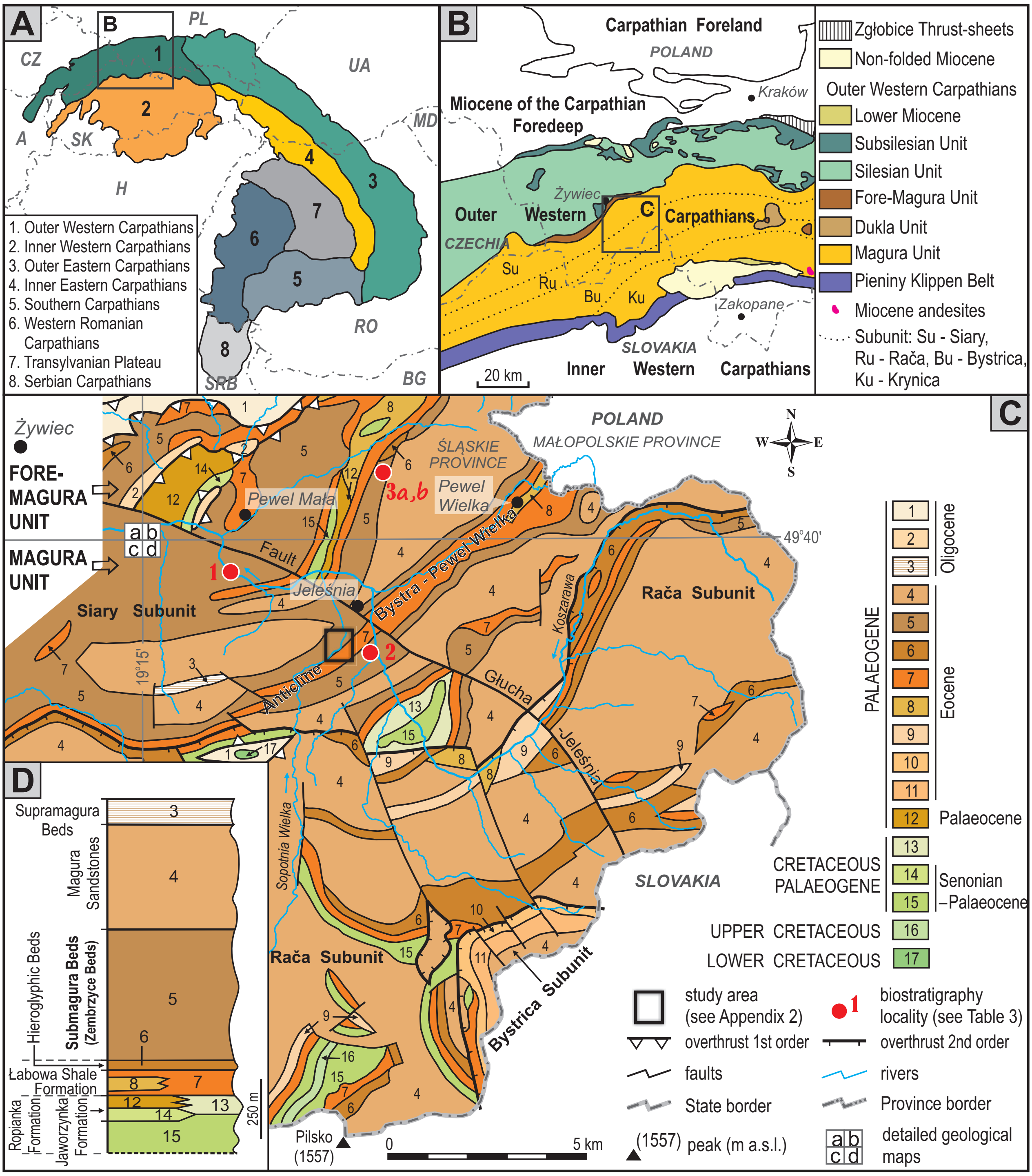


Fig. 1. Location of the study area. Explanations: **A** — Divisions of the Carpathians (after Kováč et al. 1998, simplified); **B** — Schematic tectonic map of the Outer Western Carpathians (after Żytko et al. 1988-1989; Oszczypko et al. 2008; Żelaźniewicz et al. 2011; simplified); **C** — Geological map of Jeleśnia (after Golonka & Wójcik 1978a; Golonka et al. 1979; modified): 1 — Krosno Beds, 2 — Barutka Marls, 3 — Supra-Magura Beds (Budzów Member — after Golonka 1981; Cieszkowski et al. 2006), 4 — Magura Sandstones (Wątkowa Member — after Golonka 1981; Cieszkowski et al. 2006), 5 — Sub-Magura Beds (Zembrzyce Beds — after Cieszkowski et al. 2006), 6 — Hieroglyphic Beds, 7 — Łabowa Shale Formation, 8 — Ciężkowice Sandstones (Skawce Member — after Cieszkowski et al. 2006), 9 — Pasierbiec Sandstones, 10 — Beloveža Beds (Beloveža Formation — after Oszczypko 1991; Pivko 2002; Oszczypko et al. 2005), 11 — Łącko Formation, 12 — Mutne Member, 13 — Krzyżowa Member, 14 — Jaworzynka Formation — after Oszczypko et al. 2005; Cieszkowski et al. 2006, 15 — Ropianka Formation — after Oszczypko 1991; Pivko 2002, 16 — Cebula Formation — after Pivko 2002, 17 — Cisownica Shales; Detailed Geological Map on the scale 1:50,000, sheet: a — Nescieruk & Wójcik 2014; b — Ryłko & Paul 1997; c — Burtan et al. 1959; d — Golonka & Wójcik 1978a; **D** — Lithostratigraphic profile of the Siary Unit in the Jeleśnia area: number from 3 to 8 and from 12 to 15 see Fig. 1C (after Burtan et al. 1959; Golonka & Wójcik 1978a; Ryłko & Paul 1997).

marly and sandy-muddy shales (Sikora & Żytko 1959; Golonka & Wójcik 1978a,b; Golonka 1981). Within the Ropianka Formation, there are lithosomes of thick-bedded coarse-grained sandstones from Krzyżowa (Krzyżowa Member, Senonian/Palaeocene) (Golonka & Wójcik 1978a,b). In the north-western part of the Siary Subunit, the Ropianka Formation becomes interfingered with the Jaworzynka Formation of medium bedded sandstones with interbeds of shale. In the upper part of the Jaworzynka formation, there are thick-bedded coarse-grained and gravelly sandstones from Mutne (Mutne Member, Palaeocene) (Sikora & Żytko 1959; Golonka & Wójcik 1978a,b; Golonka 1981; Chodyń 2002). Next, the profile consists of Eocene variegated shales (Łabowa Shale Formation), with occurrences of coarse or gravelly sandstones (Ciężkowice Sandstones, Skawce Member, Cieszkowski et al. 2006) belonging to the early Eocene (e.g., Książkiewicz 1966, 1974).

Stratigraphically, above the Łabowa Formation are the Hieroglyphic Beds (Middle/Upper Eocene according to Książkiewicz 1974; Beloveža Beds according to Cieszkowski et al. 2006), composed predominantly of medium and thin bedded shales with thin-bedded sandstones. The Hieroglyphic Beds are covered by the Zembrzyce Beds of Middle Eocene–Upper Eocene age (Cieszkowski et al. 2006). Within the Zembrzyce Beds, grey and green marly shales and greyish-blue marls dominate (Książkiewicz 1974; Oszczypko-Clowes 1999, 2001). The thickness of the shale beds is from 0.5 to 2.5 metres. Between shales and marls packages, there are medium-bedded to thick-bedded glauconite sandstones from 20 centimetres to 1 metre thick. The ratio between shales and sandstones is 3:1 in average and it decreases up the profile. The Zembrzyce Beds are covered by the Magura Sandstones (Late Eocene–Oligocene, Wątkowa Member, Golonka 1981; Cieszkowski et al. 2006).

The Siary Subunit profile ends with the Supra-Magura Beds (Budzów Member by Golonka 1981; Cieszkowski et al. 2006) of Oligocene age. These are mainly marly shales, sandy-muddy shales, and spongiolites, with subordinate medium and fine-grained mica sandstones (Kopciowski 1996; Oszczypko-Clowes 2001).

The Zembrzyce Beds (Zembrzyce Shale Member), Magura Sandstones (Wątkowa Sandstone Member), and Supra-Magura Beds (Budzów Shale Member) belong to the Makowska Formation according to Cieszkowski et al. (2006).

Tectonics of the study area

Within the study area, the main structural element is the Bystra-Pewel Wielka anticline (Fig. 1C), which borders the Kiczory-Bąkowa syncline to the north and the Zagrodzki Groń syncline to the south (Golonka & Wójcik 1978a,b). The axes of the anticlines and synclines run in the SW–NE direction.

Transverse dislocations play a major role (Golonka & Wójcik 1978a,b; Golonka 1981). These are dip-slip and strike-slip faults. In the study areas the large dip-slip type Głucha–Jeleśnia fault runs from the north to Slovakia (Golonka & Wójcik 1978a).

Methods

During the field studies, which were carried out in the natural exposures of the Sopotnia stream, 11 (in total ca. 76 metres long, bed by bed) detailed sedimentological logs of the Zembrzyce Beds were made (Appendix 1 and 2). Logging included the description of sedimentary structures and textures, description of colour and thickness of rock layers, HCl response, dip and strike measurements, and where possible, palaeotransport direction. The succession sections where overthrusts were observed were omitted in the interpretation of the Zembrzyce Beds depositional architecture.

The next step was to distinguish facies based on lithological features such as: grain size, thickness of beds, character of bed boundaries, and the average sandstone to mudstone ratio within the succession. Names of facies were based on facies codes in classifications of Mutti & Ricci Lucchi (1972, 1975); Walker & Mutti (1973); Mutti (1979); Pickering et al. (1989); Ghibaudo (1992) and Słomka (1995). Afterwards, within facies, subfacies were distinguished based on sedimentary structures (Table 1). Facies were grouped into facies associations (Table 2) using the textural and structural differences in the facies' vertical distribution.

The samples from Pewel Mała (sample no. 1), Jeleśnia (sample no. 2) and Pewel Ślemieńska (samples no. 3a,b) were collected for micropalaeontological (nannoplankton) investigations (Fig. 1C). The samples were derived from olive or olivish-grey, grey and brown mudstones belonging to the Zembrzyce Beds. The micropalaeontological analysis of the samples was carried out by Prof. dr. hab. Barbara Olszewska and Dr. Małgorzata Garecka (2011) from the Polish Geological Institute — National Research Institute in Cracow. For the nannoplankton examination all the samples were prepared by the standard smear slide method for light microspore observations. In addition, published results of microfauna studies were used (Golonka & Wójcik 1978a; Golonka 1981; Olszewska 1981; Leszczyński & Malata 2002).

The research permitted reconstruction of the depositional environment of the Zembrzyce Beds south of the Żywiec and the creation of a sedimentation model for these sediments.

Results

Facies of Zembrzyce Beds in the study area

Facies 1

Sediments belonging to Facies 1 represent medium to very thick-bedded gravelly sandstones. Sandstone beds usually show irregular basal surfaces covered with groove marks and flute marks (Figs. 2 and 3A). Planar surfaces occur rarely as well. The beds of this facies show: graded bedding and convolute lamination. Horizontal lamination and wavy lamination are less common. Facies 1 corresponds to subfacies A2.5, A2.7, A2.8 of Pickering et al. (1989), facies GyS of Ghibaudo

(1992), and facies SC of Słomka (1995). Within Facies 1, three subfacies were distinguished (Table 1). Sediments of Facies 1 are interpreted as the results of rapid gravel-sand deposition of high-density turbidity currents from suspension with transition to traction (Ghibaudo 1992; Słomka 1995), or from hyperconcentrated density flows (Pickering et al. 1989; Mulder & Alexander 2001; Lowey 2007), which are intermediate between Newtonian fluid flow and Bingham plastic flow (Nemec 2009).

Facies 2

Facies 2 consists mainly of medium to very thick-bedded fine-grained sandstones. Within sandstone beds, there are mud intraclasts as well as coalified plant detritus. The bottom surfaces of sandstone beds are planar or irregular (Figs. 2 and 3B). The sandstones display horizontal lamination, cross lamination, convolute lamination and sometimes wavy lamination. Sediments of this facies also display massive structure.

Table 1: Facies and subfacies description of the Zembrzyce Beds.

Facies	Subfacies
FACIES 1 GRAVELLY SANDSTONES A2.5, A2.7, A2.8 (Pickering et al.1989); GyS (Ghibaudo 1992); SC (Słomka 1995)	1.1 normally graded gravelly sandstones to convolute-laminated sandstones 1.2 normally graded gravelly sandstones to horizontal and/or wavy-laminated and convolute-laminated sandstones 1.3 normally graded gravelly sandstones
FACIES 2 SANDSTONES B (Walker & Mutti 1973; Mutti & Ricci Lucchi 1975; Pickering et al. 1989); C (Mutti 1979); S (Ghibaudo 1992; Słomka 1995)	2.1 massive sandstones 2.2 convolute-laminated sandstones 2.3 cross-laminated sandstones 2.4 horizontal-laminated sandstones 2.5 wavy-laminated sandstones 2.6 massive to horizontal-laminated and/or wavy-laminated and convolute-laminated sandstones
FACIES 3 THICK-BEDDED TO VERY THICK-BEDDED SANDSTONE-MUDSTONE COUPLETS C and D (Walker & Mutti 1973; Mutti & Ricci Lucchi 1975); C2.1 (Pickering et al. 1989); SM (Ghibaudo 1992; Słomka 1995)	3.1 horizontal to wavy-laminated and cross-laminated sandstone-mudstone couplets 3.2 very thick-bedded massive to wavy-laminated and convolute-laminated sandstone-mudstone couplets 3.3 convolute-laminated sandstone-mudstone couplets 3.4 thick-bedded massive to wavy-laminated and convolute-laminated sandstone-mudstone couplets
FACIES 4 THIN-BEDDED TO MEDIUM-BEDDED SANDSTONE-MUDSTONE COUPLETS C and D (Walker & Mutti 1973; Mutti & Ricci Lucchi 1975); D1 (Mutti 1979); C2.2 and C2.3 (Pickering et al. 1989); SM (Ghibaudo 1992; Słomka 1995)	4.1 massive to cross-laminated sandstone-mudstone couplets 4.2 massive sandstone-mudstone couplets 4.3 horizontal-laminated to convolute-laminated sandstone-mudstone couplets 4.4 convolute-laminated sandstone-mudstone couplets 4.5 wavy-laminated to convolute laminated sandstone-mudstone couplets 4.6 massive to convolute- laminated sandstone-mudstone couplets 4.7 horizontal-laminated sandstone-mudstone couplets 4.8 cross-laminated sandstone-mudstone couplets 4.9 wavy-laminated sandstone-mudstone couplets 4.10 massive to horizontal-laminated sandstone-mudstone couplets
FACIES 5 MUDSTONE-SANDSTONE COUPLETS D (Walker & Mutti 1973); D2 (Mutti & Ricci Lucchi 1975; Mutti 1979); C2.4 (Pickering et al. 1989); MS (Ghibaudo 1992; Słomka 1995).	5.1 cross-laminated mudstone-sandstone couplets 5.2 massive to horizontal-laminated and wavy-laminated mudstone-sandstone couplets 5.3 convolute-laminated mudstone-sandstone couplets 5.4 massive to convolute-laminated mudstone-sandstone couplets 5.5 massive mudstone-sandstone couplets 5.6 cross-laminated to convolute-laminated mudstone-sandstone couplets 5.7 horizontal-laminated mudstone-sandstone couplets
FACIES 6 MUDSTONES AND SANDY MUDSTONES WITH MARLS D2.3 (Pickering et al. 1986, 1989); MT (Ghibaudo 1992; Słomka 1995)	
FACIES 7 MUDSTONES AND SANDY MUDSTONES WITH THIN-BEDDED SANDSTONES	
FACIES 8 MUDSTONES AND SANDY MUDSTONES WITH IRREGULAR SANDSTONE LAYERS E (Mutti 1979)	
FACIES 9 MUDSTONES AND SANDY MUDSTONES E2.2 (Pickering et al. 1986, 1989); TM and MT (Ghibaudo 1992); MT (Słomka 1995)	

Table 2: Facies associations of the Zembrzyce Beds.

ASSOCIATIONS	FACIES	ENVIROMENT OF SEDIMENTATION	
I	1, 2, 3, 4, 5, 6	termination of distributary channel passing upward into depositional lobe	distal part of mid-fan/outer fan subdeposystem
II	2, 3, 4, 5, 6	muddy-sandy depositional lobe	outer fan subdeposystem
III	8, 9	distal part of depositional lobe (fan fringe lobes)	
IV	7, 9	lower fan (fan fringe/basin plain)	

Facies 2 corresponds to facies B of Walker & Mutti (1973) and Mutti & Ricci Lucchi (1975); facies B of Pickering et al. (1989); facies C of Mutti (1979); facies S of Ghibaudo (1992), and facies S of Słomka (1995) (Table 1). These sediments are characteristic for the rapid deposition of sandy high-density turbidity currents with transition to traction (Ghibaudo 1992; Słomka 1995) or they result from hyperconcentrated density flows (Pickering et al. 1989; Mulder & Alexander 2001).

Facies 3

Facies 3 consists of sandstone-mudstone couplets, with sandstones dominating. This facies forms bipartite beds that comprise a lower sandy division and an upper muddy division. The sandstone beds are 30–120 cm thick, whereas the thickness of the mudstone beds ranges 15–20 cm. The thick-bedded and very thick-bedded sandstones are fine-grained and show planar or sometimes irregular basal surfaces (Figs. 2 and 3C). Within sandstone beds, there are mud intraclasts as well as coalified plant detritus. Beds of sandstones are characterized predominantly by horizontal lamination, cross lamination and convolute lamination. Some beds are wavy-laminated or non-laminated. The interbeds of mudstones and sandy mudstones are characterized by parallel and wavy laminations. Facies 3 corresponds to facies C and D of Walker & Mutti (1973) and Mutti & Ricci Lucchi (1975); subfacies C2.1 of Pickering et al. (1989); facies SM of Ghibaudo (1992), and facies SM of Słomka (1995) (Table 1). These sediments are a result of concentrated density flows (Pickering et al. 1989).

Facies 4

Facies 4 consists of sandstone–mudstone couplets, with sandstones dominating (Figs. 2 and 3D). The medium and thin-bedded sandstones are fine-grained. Sandstone beds show planar or sometimes irregular basal surface. Coalified plant detritus is observed within sandstones beds. Beds of sandstones usually show convolute lamination, cross lamination and horizontal lamination. Massive structure and horizontal lamination usually occur in the lower part of beds. Interbeds of mudstones and sandy mudstones reveal parallel and wavy laminations. Facies 4 corresponds to facies C and D of Walker & Mutti (1973) and Mutti & Ricci Lucchi (1975); facies D1 of Mutti (1979); subfacies C.2.2 and C.2.3 of Pickering et al. (1989); facies SM of Ghibaudo (1992); and facies SM of Słomka (1995). Within Facies 4, ten subfacies were distinguished (Table 1). Sediments of Facies 4 are interpreted as a result of deposition of different-density turbidity currents with rapid transition to traction of very fine-grained material (Ghibaudo 1992; Słomka1995).

Facies 5

Sediments belonging to Facies 5 represent mudstone–sandstone couplets with mudstones dominating (Figs. 2 and 3E). Beds show irregular or planar basal surfaces. The mudstone layers are up to about 15–20 cm thick, whereas the thickness of sandstone beds ranges from 6–12 cm. Mudstones and sandy mudstones reveal parallel lamination. Sandstones are fine-grained, with evidence of coalified plant detritus. The commonest subfacies are: cross-laminated mudstone–sandstone couplets, convolute-laminated mudstone–sandstone couplets, massive mudstone–sandstone couplets, massive to convolute-laminated mudstone–sandstone couplets, massive to horizontal-laminated and wavy-laminated mudstone–sandstone couplets, cross-laminated to convolute-laminated mudstone–sandstone couplets, horizontal-laminated mudstone–sandstone couplets (Table 1). Facies 5 corresponds to facies D of Walker & Mutti (1973); subfacies D2 of Mutti & Ricci Lucchi (1975); subfacies C2.4 of Pickering et al. (1989); subfacies D2 of Mutti (1979); facies MS of Ghibaudo (1992); and facies MS of Słomka (1995). Within Facies 5, seven subfacies were distinguished (Table 1). Sediments of Facies 5 were formed by rapid deposition of dilute turbidity currents with transition to traction, sometimes with reworking of very-fine detrital material by bottom currents (Słomka 1995), or from low-density turbidity currents (Ghibaudo 1992).

Facies 6

Facies 6 represents grey, greyish-olive, and brownish sandy mudstones and mudstones with parallel lamination and occasional interbeds of marls (Figs. 2 and 3F). Interbeds of mudstones and sandy mudstones reveal parallel laminations. Facies 6 corresponds to facies D2.3 of Pickering et al. (1986, 1989); facies MT of Ghibaudo (1992); and facies MT of Słomka (1995) (Table 1). The sediments of Facies 6 are interpreted as a result of fine-grained deposition laid down by suspension or by low-density turbidity currents (Ghibaudo 1992; Słomka 1995).

Facies 7

In facies 7, olive and grey mudstones with parallel lamination dominate over sandy mudstones. There are also thin-bedded horizontal laminated and massive sandstones (Figs. 2 and 4A). Thin layers of cross-laminated sandstones occur occasionally within facies 7. The mudstones are sandy to different degrees. The sediments of Facies 7 are interpreted as a result of deposition from suspension of fine-grained deposits (Słomka 1995). This sedimentation was sometimes interrupted by deposition from low-density turbidity currents.

Facies 8

Facies 8 consists of grey and rarely brown mudstones and thin-bedded sandy mudstones. Within facies 8, there are very thin bedded sandstones with wavy and cross lamination. Sandstone beds show irregular surfaces (Figs. 2 and 4B). The sediments of this facies correspond to facies E of Mutti (1979) and they are interpreted as a result of deposition from suspension of fine-grained deposits (Słomka 1995). This

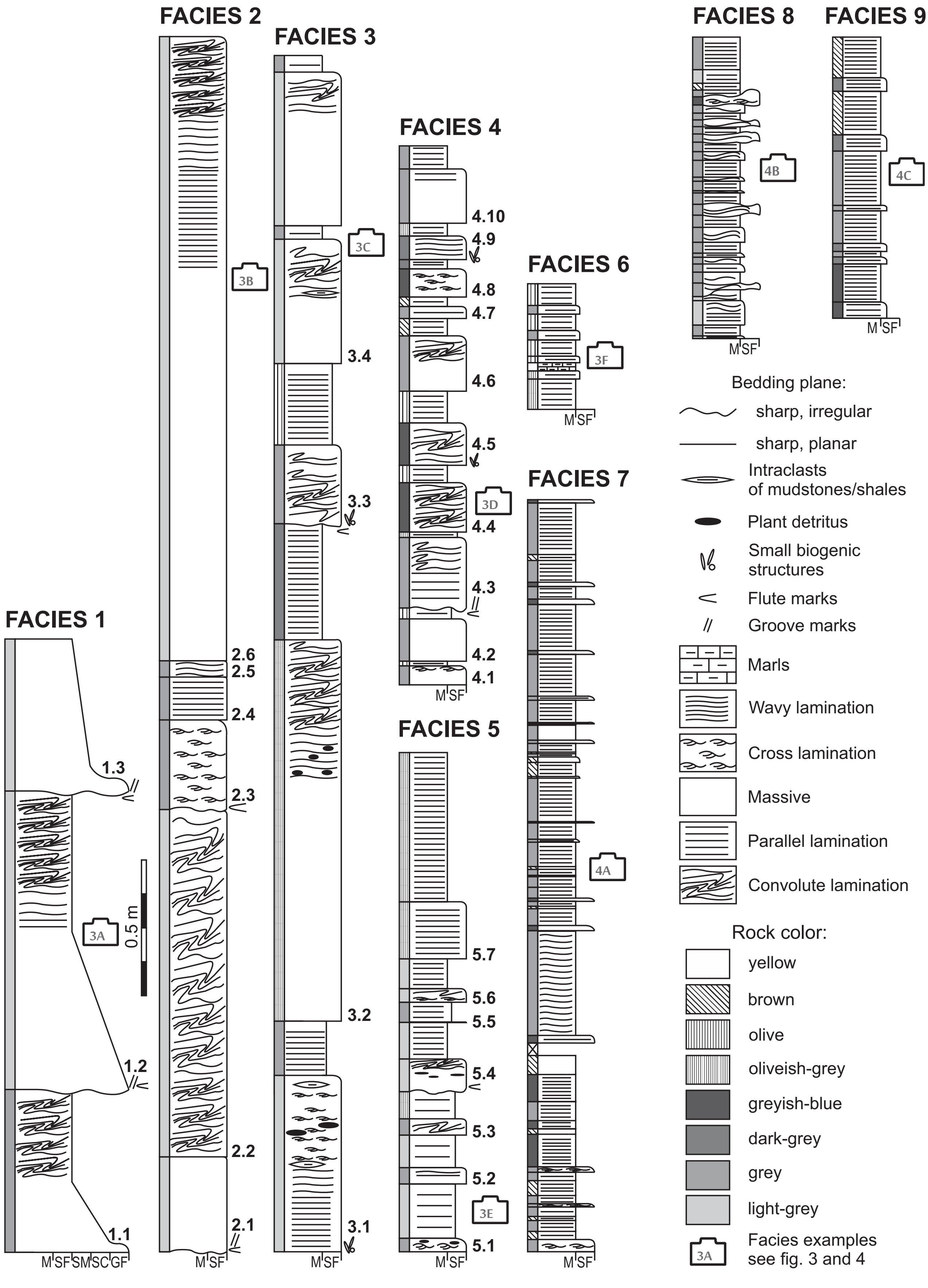


Fig. 2. Facies of the Zembrzyce Beds in the study area: numbers from 1.1 to 5.7 — subfacies (see Table 1).

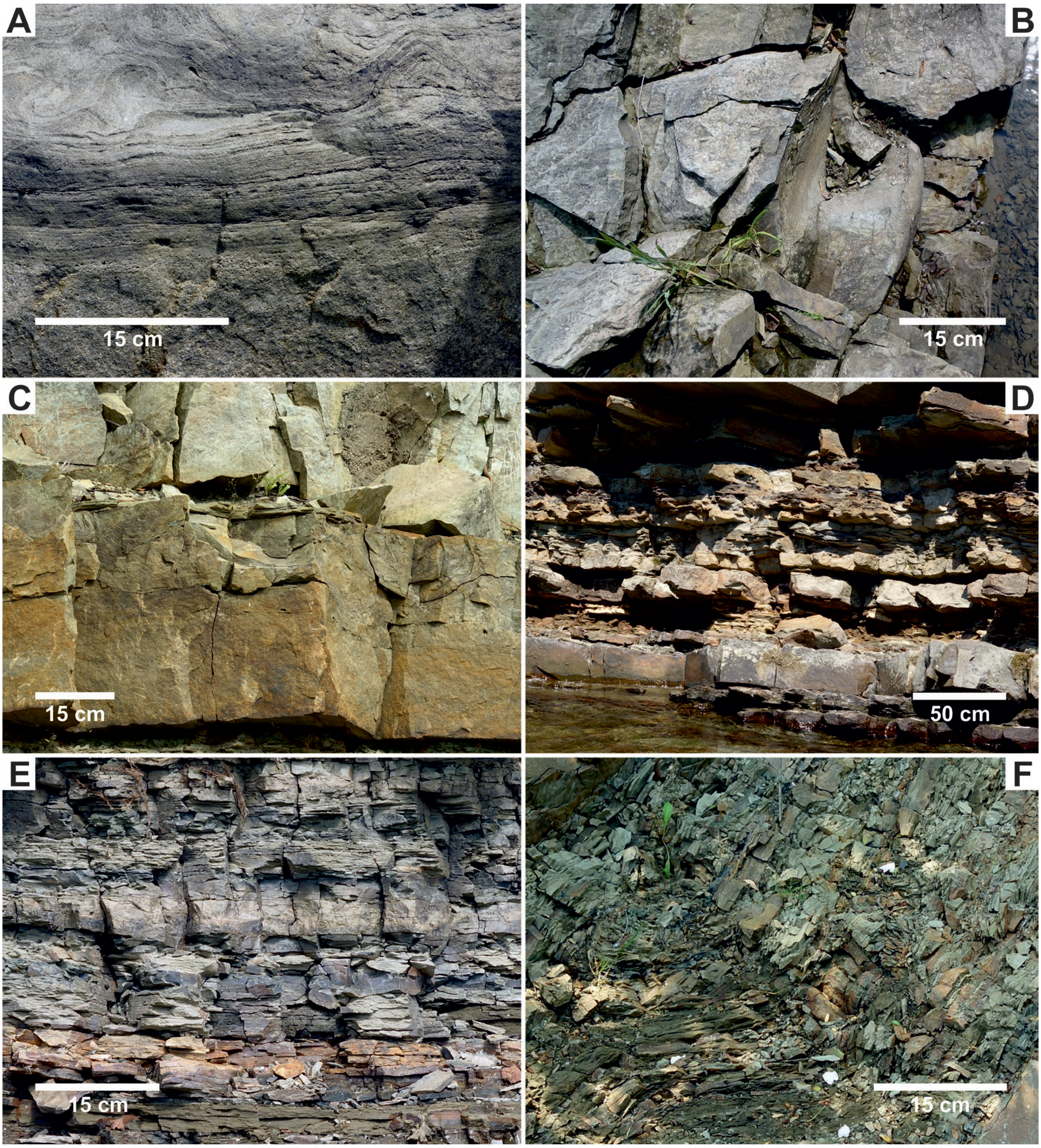


Fig. 3. Facies examples of the Zembrzyce Beds; **A** — facies 1 (gravelly sandstones); **B** — facies 2 (sandstones); **C** — facies 3 (thick-bedded to very thick-bedded sandstone-mudstone couplets); **D** — facies 4 (thin-bedded to medium-bedded sandstone-mudstone couplets); **E** — facies 5 (mudstone-sandstone couplets); **F** — facies 6 (mudstones and sandy mudstones with marls).

sedimentation was sometimes interrupted by deposition from different-density turbidity currents.

Facies 9

Facies 9 consists of grey, dark grey, greyish-blue and rarely brown mudstones with thin-bedded sandy mudstones (Figs. 2 and 4C). Interbeds of mudstones and sandy mudstones reveal parallel laminations. Facies 9 corresponds to facies E2.2 of Pickering et al. (1986, 1989); facies TM and MT of Ghibaudo (1992); and facies MT of Słomka (1995). The sediments of this facies are interpreted as a result of fine-grained deposits laid down by suspension, or by low-density turbidity currents (Ghibaoudo 1992; Słomka, 1995).

Facies associations of the Zembrzyce Beds in the study area

Based on facies features, four facies associations of the Zembrzyce Beds in the Siary Subunit were distinguished (Fig. 5).

The beds of gravelly sandstones and sandstones are deposits of high-concentrated turbidity currents sensu Lowe (1982), or concentrated density flows sensu Mulder & Alexander (2001). The medium and thin-bedded sandstone–mudstone couplets as well as the mudstone–shale couplets and the beds of graded shales are deposits of low-concentrated turbidity currents sensu Lowe (1982), or turbidity currents sensu Mulder & Alexander (2001), whereas the varicoloured shales and muddy shales that occur in the top part of the massive shale layers and which underline sandstone beds are hemipelagites and background sediments in the entire succession.

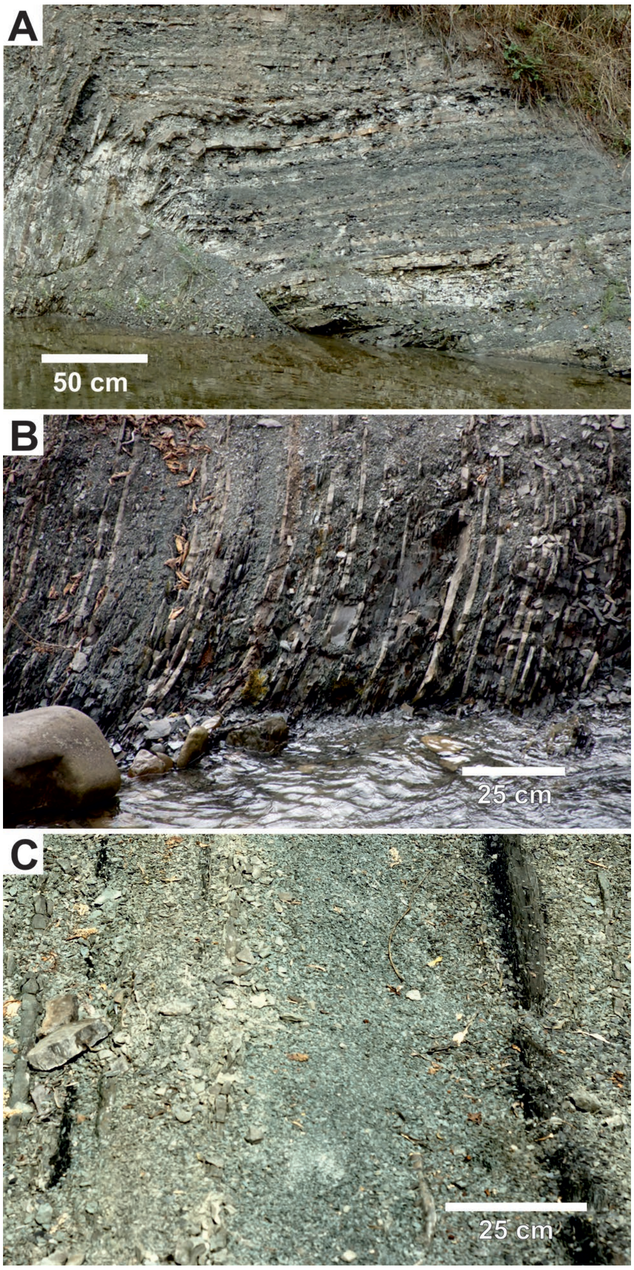


Fig. 4. Facies examples of the Zembrzyce Beds; **A** — facies 7 (mudstones and sandy mudstones with thin-bedded sandstones); **B** — facies 8 (mudstones and sandy mudstones with irregular sandstone layers); **C** — facies 9 (mudstones and sandy mudstones).

Association I — termination of distributary channels/depositional lobes

This facies association is composed of gravelly sandstones, sandstone–mudstone couplets, mudstone–sandstone couplets and occasionally mudstones and sandy mudstones with marl facies (Facies 1, 2, 3, 4, 5 and occasionally 6) (Table 2). The estimated proportion of sandstones is from 57 to 71 %, whereas mudstones make up 29 to 43 %. Deposition of these sediments took place in the mid part of a sub-marine fan depositional system. Negative facies sequences (i.e., decreasing upward thickness of beds and grain size) occur in the lower part of the sedimentary succession. However, in the upper part of the sedimentary succession, the low number of positive facies sequences (i.e., increasing upward thickness of layers and grain size) suggest that these sediments represent the distal part of the mid fan, probably near the final part of distributary channels passing upward into depositional lobes.

Association II — depositional lobe

In this facies association, mudstone and mudstone–sandstone couplets and thin-bedded to medium-bedded sandstone–mudstone couplets dominate (Facies 4, 5 and 6), with a small share of thick-bedded sandstone–mudstone couplets and sandstones (Facies 2 and 3) (Fig. 5 and Table 2). The estimated proportion of sandstones is from 40 to 47 %, whereas mudstones make up 53 to 60 %. This type of sediment was deposited in the distal (outer) part of the depositional system, probably within depositional lobes (in their distal part), which are responsible for the positive facies sequences within the sedimentary succession. Most likely, these are outer fan deposits passing upward into deposits of muddy or muddy–sandy depositional lobes.

Association III — distal lobes (fan fringe lobes)

Association III comprises mudstones and sandy mudstones with intercalations of sandstone bodies with lenticular geometry (Facies 8 and 9) (Fig. 5 and Table 2). The percentage of sand-size grains ranges from 9 to 20 %, and the percentage of mud-size grains ranges from 56 to 77 %. Deposition of this sediment type is typical for the distal (outer) part of a submarine fan depositional system — the fringe lobes.

Association IV — lower fan/basin plain (fan fringe/basin plain)

Association IV consists of mudstones and sandy mudstones with intercalations of thin-bedded sandstones (Facies 7 and 9) (Fig. 5 and Table 2). The estimated proportion of mudstones

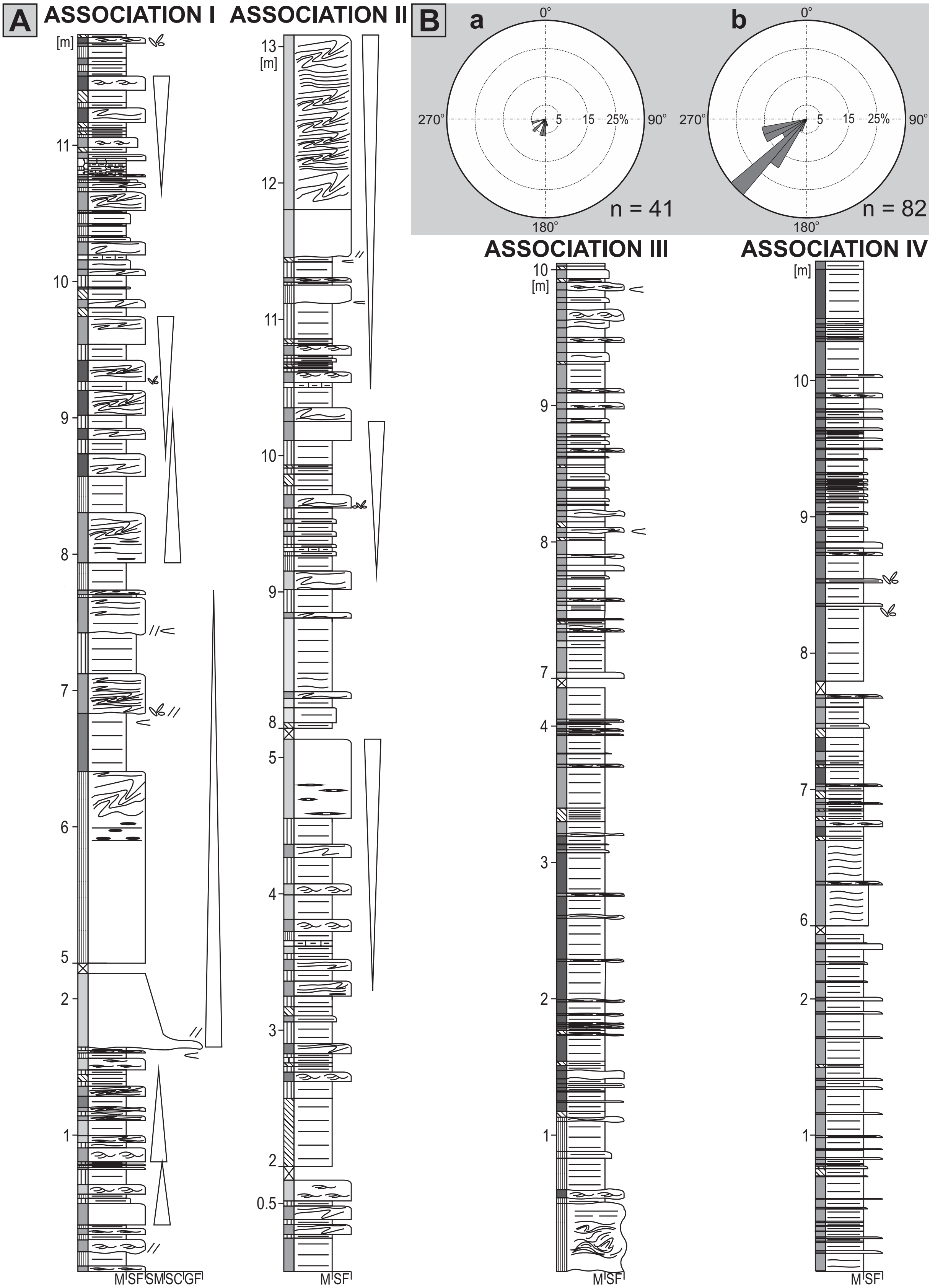


Fig. 5. The synthetic characteristic patterns of facies associations based on sedimentological study of the Zembrzyce Beds (**A**) and palaeotransport directions in the Zembrzyce Beds (**B**): **a** — based on literature data (Sikora & Żytko 1959), **b** — measured during field studies and based on literature data (Wójcik 2013); legend for facies association see Appendix 1 and 2.

is 69–89 %, whereas sandstones do not exceed 10 %. Deposition of this type of sediment is characteristic for the distal (outer) part of a sub-marine fan depositional system — the fan fringe.

Biostratigraphy

In the western part of the Siary Subunit the age of the Zembrzyce Beds was determined as Middle–Late Eocene and even as Middle Eocene–Early Oligocene (Sikora & Żytko 1959; Golonka & Wójcik 1978a; Chodyń 2002).

Based on our micropalaeontological investigations in the Jeleśnia area, the age of the Zembrzyce Beds in the study area was determined as the Late Eocene (zones NP19–20) (Tables 3 and 4) (Garecka 2011).

Discussion

The main depositional architectural elements of the Zembrzyce Beds

The submarine fan deposystem comprises three sub-deposystems: inner-fan, mid-fan and outer-fan. The mid-fan sub-deposystem is the transitional part between the inner-fan and outer fan. It is characterized by numerous distributary channels. The outer-fan sub-deposystem is formed beyond the channel-featured mid-fan sub-deposystem (Zhang et al. 2015).

In the study area only the mid-fan and outer-fan sub-deposystems are present. We classified three architectural elements as terminations of distributary channel-depositional lobes (distal part of mid-fan/outer fan), depositional lobes and distal lobes (outer fan).

Termination of distributary channel/lobes

Association I occurs in the lower part of the channel succession. Association I is an example of sediments belonging to the termination of a distributary channel with transition to depositional lobe succession. This association is represented by gravelly sandstones, sandstones and sandstone–mudstone couplets or mudstone–sandstone couplets. Association I is characterized by vertical sediment differentiation. Sediments that are characterized by the presence of: muddy clasts and coalified plant detritus, negative facies sequences in the lower part of sedimentary succession and positive facies sequence in the upper part of the sedimentary succession. In association I, in the lower part of the sedimentary succession, thick-bedded to very thick-bedded channel sandstones and gravelly sandstones occur, whereas, in the upper part of the sedimentary succession usually thin-bedded to medium-bedded sandstones occur. Sandstone beds are massive, parallel-laminated, cross-laminated and convolute-laminated. Basal surfaces of beds are sharp and flat, or locally irregular. Mudstones are parallel-laminated. Erosional structures at the base of sandstones are attributed to the erosion by heads of high-velocity turbidity currents. Mudstone beds of laminated intervals were formed when distributary channels kept changing their positions (Zhang et al. 2015).

Lobes

Association II represents muddy-sandy depositional lobes. Sediments are characterized by the presence of positive facies sequences. This association mostly consists of sandstone–mudstone couplets or mudstone–sandstone couplets, but sometimes between sandstone–mudstone couplets and mudstone–sandstone couplets, sandstones and episodically gravelly sandstones occur. The difference of association I from association II is that association I is characterized by the prevalence of sandstone-size grains in relation to mudstone-size grains, whereas association II is characterized by the reverse ratio of the above fractions. Sandstone beds mostly show parallel surfaces. In laminated intervals, cross lamination, convolute lamination, horizontal lamination are common. Sometimes sandstone beds show erosional basal surfaces with flute casts or tool marks on the base. Sandstones beds are rarely massive with muddy clasts or with deformation of the lamina. The occurrence of thick-bedded sandstones and gravelly sandstones together with the great thickness of beds of sandstone–mudstone couplets, mudstone–sandstone couplets and mudstones can represent the residue after channel migration or fill end distributary channel on depositional lobes. Association II is characterized by vertical sediment differentiation which can be explained by cutting off and lobe migration within the sub-marine fan. There were probably elongated depositional lobes that laterally migrated.

Distal lobes

Association III represents sediments from the fan fringe lobes. In this facies association, mudstones dominate with a low percentage of sandstones. The occurrence of sandstone bodies with lenticular geometry is associated with the migration of lobes during the Zembrzyce Beds deposition.

Association IV is related to sedimentation located far from a source area. In this association, mudstones dominate. The presence of this sediment type is typical of sedimentation in the most distal part of lobes with the transition to sediments of fan fringe. In contrast to association III, the greater share of mudstones represents the transition to more stable sediments of low-density turbidity currents, and the presence of thin-layer (thin-bedded) sandstones which represent interfingering of sediments from the hemipelagic environment with those of the fan fringe lobes.

Depositional system of the Zembrzyce Beds

Based on the characteristics of the distinguished associations, it was determined that the Zembrzyce Beds in the study area were formed within the distal part of the depositional

Table 3: Distribution of calcareous nannoplankton recorded in the investigated samples (Garecka 2011).

species / samples		*Braarudosphaera bigelowii*	*Braarudosphaera* sp.	*Chiasmolithus oamaruensis*	*Chiasmolithus* sp.	*Clausicoccus subdistichus*	*Coccolithus eopelagicus*	*Coccolithus pelagicus*	*Corannulus germanicus*	*Cribrocentrum reticulatum*	*Cyclicargolithus floridanus*	*Cribrocentrum coenurum*	*Cribrocentrum* sp.	*Dictyococcites callidus*	*Discoaster saipanensis*	*Dictyococcites bisectus*	*Discoaster barbadiensis*	*Dictyococcites scrippsae*	*Dictyococcites* sp.	*Discoaster tanii*	*Discoaster* sp.	*Ericsonia cava*	*Ericsonia formosa*	*Helicosphaera compacta*	*Isthmolithus recurvus*	*Lanternithus minutus*
Pewel Mała	1		×		×	×	×	×		×	×			×	×	×		×			×		×	×	×	
Jeleśnia	2		×		×			×		×				×	×	×				×	×	×	×		×	
Pewel Ślemieńska	3a				×			×		×		×	×	×		×			×						×	
	3b	×	×	×	×			×	×		×	×		×	×	×	×			×					×	×

species / samples		*Markalius inversus*	*Neococcolithes minutus*	*Neococcolithes* sp.	*Pontosphaera latelliptica*	*Pontosphaera multipora*	*Pontosphaera* sp.	*Reticulofenestra hillae*	*Reticulofenestra umbilica*	*Reticulofenestra dictyoda*	*Reticulofenestra* sp.	*"small reticulofenestrids"*	*Rhabdosphaera* sp.	*Rhabdosphaera tenuis*	*Sphenolithus moriformis*	*Sphenolithus spiniger*	*Sphenolithus moriformis*	*Sphenolithus* sp.	*Transversopontis pulcher*	*Thoracosphaera operculata*	*Thoracosphaera heimii*	*Thoracosphaera operculata*	*Thoracosphaera saxea*	*Thoracosphaera* sp.	*Zygrhablithus bijugatus*	fragments of cocoliths
Pewel Mała	1					×	×		×	×	×	×	×		×	×	×	×		×	×	×		×		×
Jeleśnia	2	×		×	×			×	×	×	×						×								×	×
Pewel Ślemieńska	3a								×	×	×							×								×
	3b		×			×	×		×	×			×	×	×		×		×				×	×	×	×

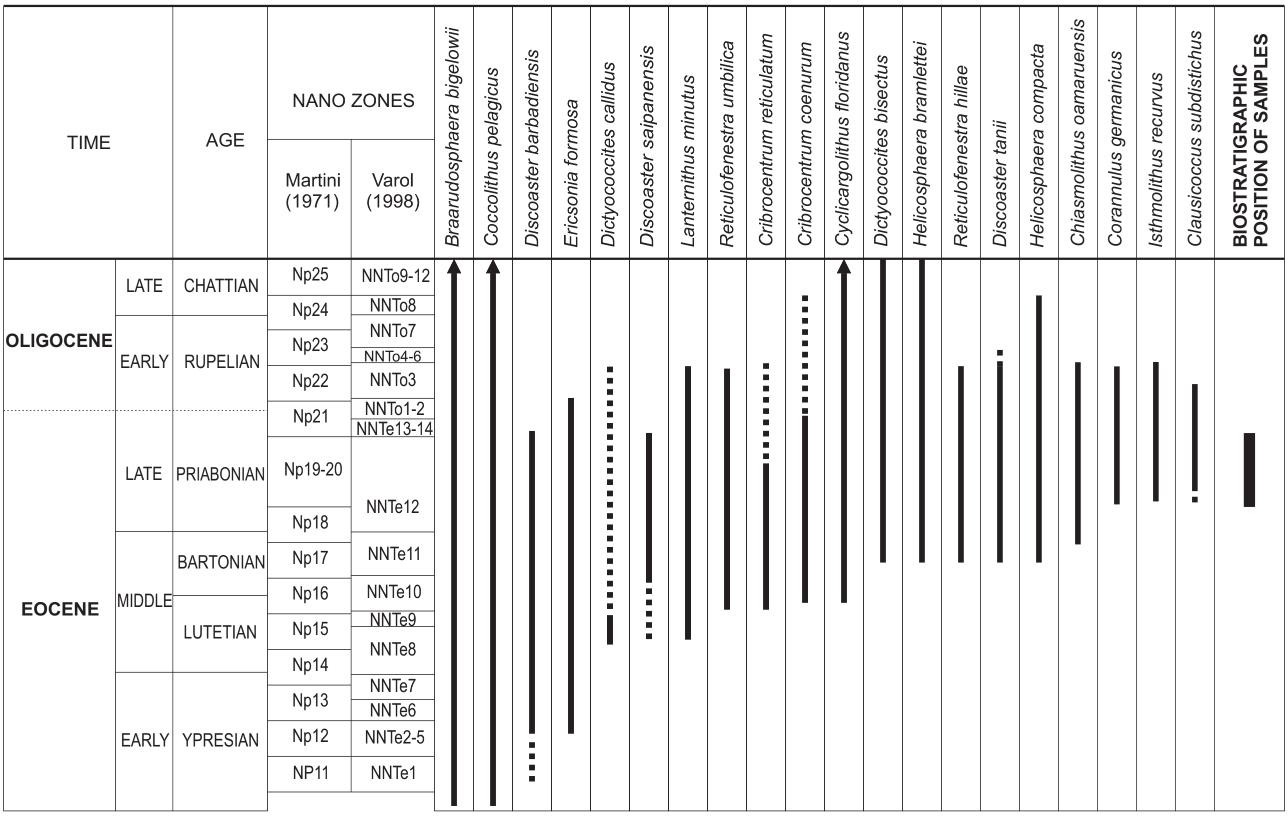
system as result of lateral migration of distributary channels and lobes stacked on top of each other. Also, in the eastern part of the Siary Subunit (near Gorlice) Kopciowski (2007) defined the Zembrzyce Beds as sediments that were accumulated as a result of turbidity currents within the distal part of a mud-rich submarine fan and the abyssal plain. According to the author, the following features confirm this statement: sandy low-density turbidites and muddy turbidites within hemipelagic sediments; the increase and decrease in layer thickness within the sedimentary complex, and the extensive distribution and presence of manganese ores within green shales in the sedimentary basin.

In total, sediment features indicate that the Zembrzyce Beds were accumulated by different gravity flows in a deep-marine environment (multiple source, mud/sand-rich ramp according to Reading & Richards' 1994 classification). The following features of the Zembrzyce Beds provide evidence for this statement: the constant transport direction of clastic sediments from NE; the simultaneous distribution of high- and low-density turbidity currents and hyperconcentrated density flows; the asymmetrical increase and decrease of layer thickness and well-sorted thick- and very thick-bedded sandstones; the continuous distribution of the Zembrzyce Beds in the Siary zone. Similar statements were made by Warchoł (2007), though, his interpretation refers not only to the Zembrzyce Beds but also to the overlying deposits considered in common as the Magura Beds (Zembrzyce Beds and Wątkowa Sandstones — sediments of distributary channels and depositional lobes dominated by sand and Budzów Shales — sediments of depositional lobes dominated by mud with the participation of sedimentation in smaller channels). The continuous cover of sediments and the linear layout of source area indicate that the depositional system has common features with those of a deep-sea ramp and a drape at the base of the slope. Leszczyński & Malata (2002) were the first to interprete the whole succession called by them Magura Beds in glauconitic facies as a submarine ramp deposits. Noteworthy, the almost exclusively shaly deposits distinguished as the Szymbark Shales, coeval with the Zembrzyce Beds (Sub-Magura Beds), described by Leszczyński & Malata (2002), Leszczyński et al. (2008) near Gorlice, were interpreted mostly as sediments of muddy turbidity currents (hemiturbidite) and hemipelagites which were deposited in the form of a cover, in the marginal part of the Magura Basin.

According to Leszczyński & Malata (2002) the Siary zone was a basin surrounded by the margins of the Magura basin in the north and by the northward sloping bottom of the Rača zone in the south. Its bottom formed a ramp. This ramp may have extended along the margins of the Magura basin, and on the west encroached on the Rača zone. Intensive resedimentation of clastic material by different mass gravity flows took place during sedimentation of the entire succession in the western part of the Siary zone and points to intensive erosion of the source area. Sedimentary conditions and sedimentation development in the Siary zone, as well as remaining parts of the Magura Basin were controlled by subduction roll-back. What is more, the authors claim that diachronism of the Magura Beds between the western and eastern part of the Siary Subunit and palaeotransport directions indicated sedimentation controlling by basin subsidence and migration of the subsidence centre obliquely to the Siary Subunit from the west to the east. It drove transpression in the Magura Basin, which resulted there in accretionary wedge progress and expanded subsidence in front of the accretionary wedge. At the same time, the margins of the Magura Basin underwent uplifting (Leszczyński & Malata 2002).

In the study area during sedimentation of the Zembrzyce Beds the depositional conditions were controlled by the tectonics as well as the global sea level changes. Tectonic development (flexural subsidence) during the Late Eocene influenced the topography of the basin floor, uplift of source areas and northward migration of depocentres. Many faults, horst and grabens have been formed and primary elements of tectonics have been reactivated. The basin floor was very varied. There

Table 4: Stratigraphic range of selected species of the calcareous nannoplankton and biostratigraphic position of analysed samples (Garecka 2011).



were ridges, which were source areas and provided material to the basin. The ridges were underwater, as well as emerged on the surface. The features of sediments indicate that the fan deposystem can be classified as a mud/sand-rich ramp sensu Reading & Richards (1994). The fan deposystem is characterized by moderate size, 5–75 km long, lobate shape, the slope gradient 7–35 m/km, moderate and moderate/small size source area, channel system: multiple leveed channels with meandering to straight platform.

Palaeogeography of Magura Basin during the Zembrzyce Beds sedimentation

The opening time of the Magura Basin is still under discussion (Oszczypko 1992; Oszczypko et al. 2015). The Early–Middle Jurassic opening of the Magura Basin was probably coeval with the South-Penninic–Piedmont–Ligurian Ocean opening (Schmid et al. 2005; Oszczypko et al. 2015). The Magura Basin domain was divided by the Czorsztyn Ridge into the NE and SE parts. The NE part was occupied by the Magura Basin, an equivalent of the north-Penninic (Valais) domain, whereas the SE arm was occupied by the Pieniny Basin, also known as the Vahicum Oceanic Rift (south Penninic domain) (Oszczypko 1992, 2004). The Magura Basin was limited by the European shelf to the north and it passed into the Ceahlau–Severin Ocean towards the SE (Oszczypko et al. 2015).

During the Late Cretaceous–Palaeocene time, the Magura Basin was modified probably by folding and thrusting processes taking place in the Central Carpathians and the Pieniny Klippen Belt (Plašienka 2014a, b; Oszczypko et al. 2015). The Magura Basin was transformed into several sub-basins with different size, bathymetry, floor morphology and tectonic activity. Particular sub-basins were supplied with clastic materials derived from intrabasinal source areas and marginal land parts (Plašienka 2014a, b; Oszczypko et al. 2015). To the north, the Magura Basin was limited by the Silesian Cordillera. The problem of the southern margin of the Magura Basin is still under consideration. In general, it is designated as the northern boundary of the Pieniny Klippen Belt (Oszczypko et al. 2015).

During the Palaeocene, the Inner Western Carpathian Orogenic Wedge reached the southern margin of the Magura Basin, which caused the subsidence and collapse of the Pieniny Klippen Belt and southwards shift of the Magura Basin. The migrating load of the Magura and the Pieniny Klippen Belt accretionary wedge caused further subsidence and a shift of depocentres to the north (Oszczypko 2004). In the Middle Eocene–Late Eocene, the sedimentation in the Magura Basin was controlled by many processes: (i) tectonic movements, (ii) the progress of the subduction within the southern margin of the Magura Basin, (iii) by local sediment supply and (iv) by the global glacioeustatic fall of sea level (Oszczypko 2004;

Teťák 2008). The Magura Basin floor was segmented by longitudinal synsedimentary depressions and lifted plains (Teťák 2008, 2010).

Palaeotransport directions (literature data and data measured during field studies) as well as the distribution of facies indicate the Silesian Cordillera as a source of clastic material from the NE for the Zembrzyce Beds (Figs. 5 and 6). The Siary sub-basin was limited by slopes of the Silesian Cordillera to the north (Leszczyński & Malata 2002; Warchoł 2007) (Fig. 6). The southern margin of the Siary sub-basin was probably limited by synsedimentary faults separating the Siary domain from the Rača sub-basin (Teťák 2008, 2010).

In the western part of the Siary sub-basin, increasing thickness of the Zembrzyce Beds sediments was observed, in contrast to the eastern area. Such diversity was related to the inclination of the whole Magura Basin axis towards the west (Fig. 6). The depositional area belonging to the Siary sub-basin was controlled by the influence of eustatic sea level

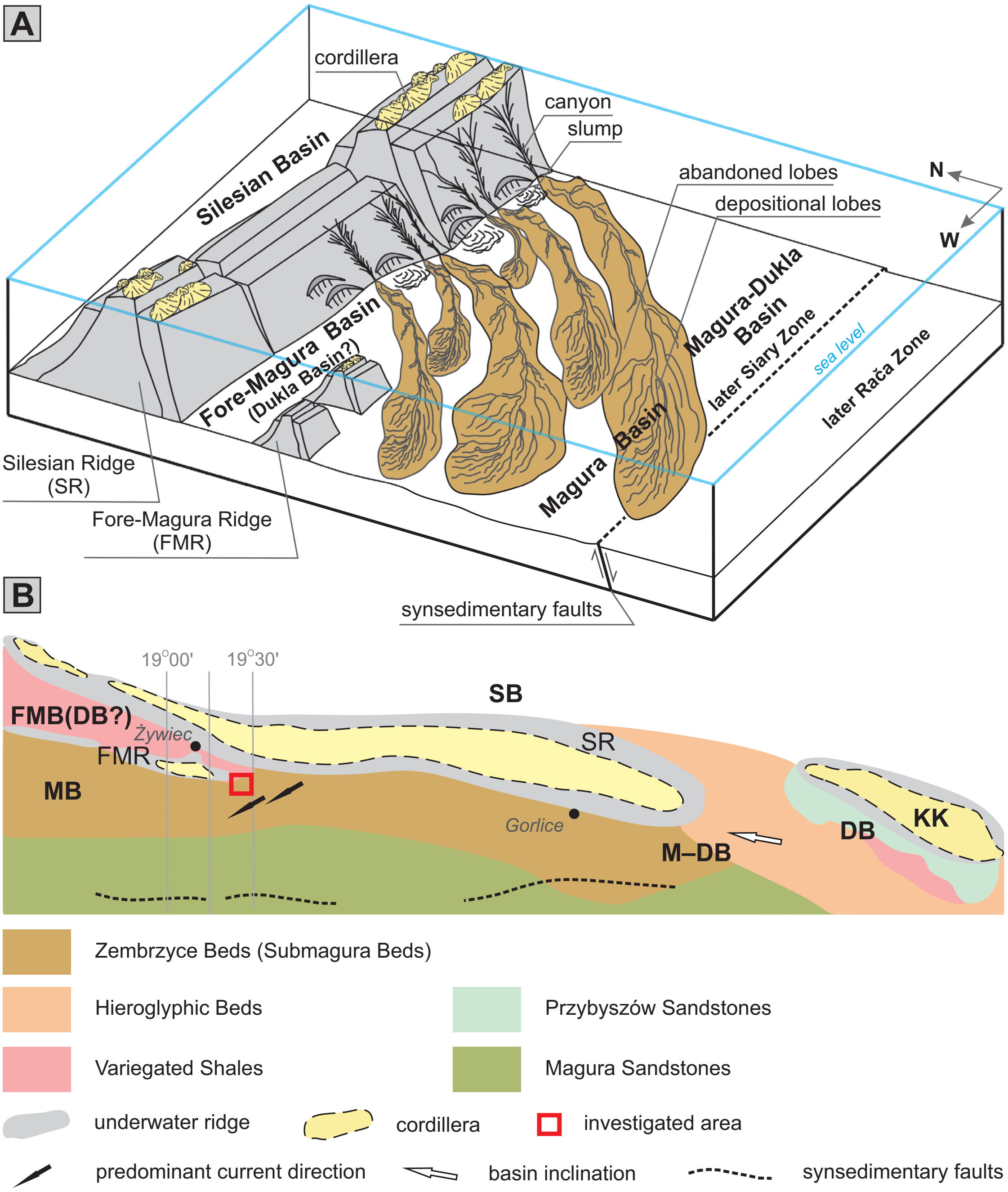


Fig. 6. Simplifed model of deposition system of the Zembrzyce Beds (multiple mud/sand-rich ramp) (**A**) and simplified palaeogeographical sketch of Magura Basin during Zembrzyce Beds deposition (**B**) (Late Eocene): FMB(DB?) — Fore-Magura Basin (Dukla Basin?); SB — Silesian Basin; MB — Magura Basin; M–DB — Magura–Dukla Basin; DB — Dukla Basin; KK — Kuman Ridge (after Książkiewicz 1962; Kopciowski 2007; Warchoł 2007; Teťák 2010; Jankowski et al. 2012; modified)

changes. During sedimentation of the Zembrzyce Beds, the relative sea level was high (highstand systems tract — maximum transgression), and the CCD was lowered. Kopciowski (2007) indicates that high similarity of sediments in the Siary Subunit and Dukla Subunit allow us to suppose that the sedimentation of depositional systems was related to the same sub-basin occurring within the Carpathian Basin. Both areas were subjected to the same source areas controlled by relative sea-level changes (Kopciowski 2007). Similar statements were written by Oszczypko et al. (2015), since the Late Cretaceous to the Late Eocene, both the Dukla and Magura sub-basins were characterized by the same depositional pattern (Inoceramian facies, Beloveža and Zlín formations).

Conclusions

1. In the study area, four main facies associations and nine lithofacies were identified and interpreted. The submarine fan deposystem comprises two subdeposystems of mid-fan and outer-fan. We classified three architectural elements: termination of distributary channel-depositional lobe (distal part of mid-fan/outer fan), depositional lobe and distal lobes (outer fan).
2. The sediments of the studied succession were deposited by high- and low-density turbidity currents and hyperconcentrated density flows sensu Mulder & Alexander (2001) with trace participation of sediments of depositional background (pelagites and hemipelagites).
3. The western part of the Siary Subunit is characterized by a multiple source, mud/sand rich ramp sensu Reading & Richards (1994).
4. The Zembrzyce Beds are sediments of the distal (outer) part of the depositional system: sediments of distributary channel terminations with transition to depositional lobes, sediments of migrating muddy-sandy depositional lobes, sediments of the fan fringe lobes and sediments from the fan fringe/basin plain. This system consisted of several elongated lobes stacked on top of each other that were active at the same time. The lobes migrated laterally and retreated or decayed. The massive and coarse-grained, thick-bedded sediments were formed in the central part of the lobe, whereas thin-bedded sediments represent the retreat of the lobes. The hemipelagic sediments represent the far distal part of the lobes and sediments that mixed with the abyssal plain sediments.
5. The Zembrzyce Beds were deposited above the CCD (Uchman et al. 2006).
6. The sediments of the Zembrzyce Beds were related probably to a high-stand system tract (Kopciowski 2007).
7. The sedimentary conditions and sedimentation development of the Zembrzyce Beds were controlled by tectonic movements, the progress of the subduction to the south and by the global sea level changes (cf. Leszczyński & Malata 2002; Oszczypko 2004; Teťák 2008).
8. The examined samples from the Zembrzyce Beds have shown that the sampled beds are of Late Eocene (zones NP19–20).

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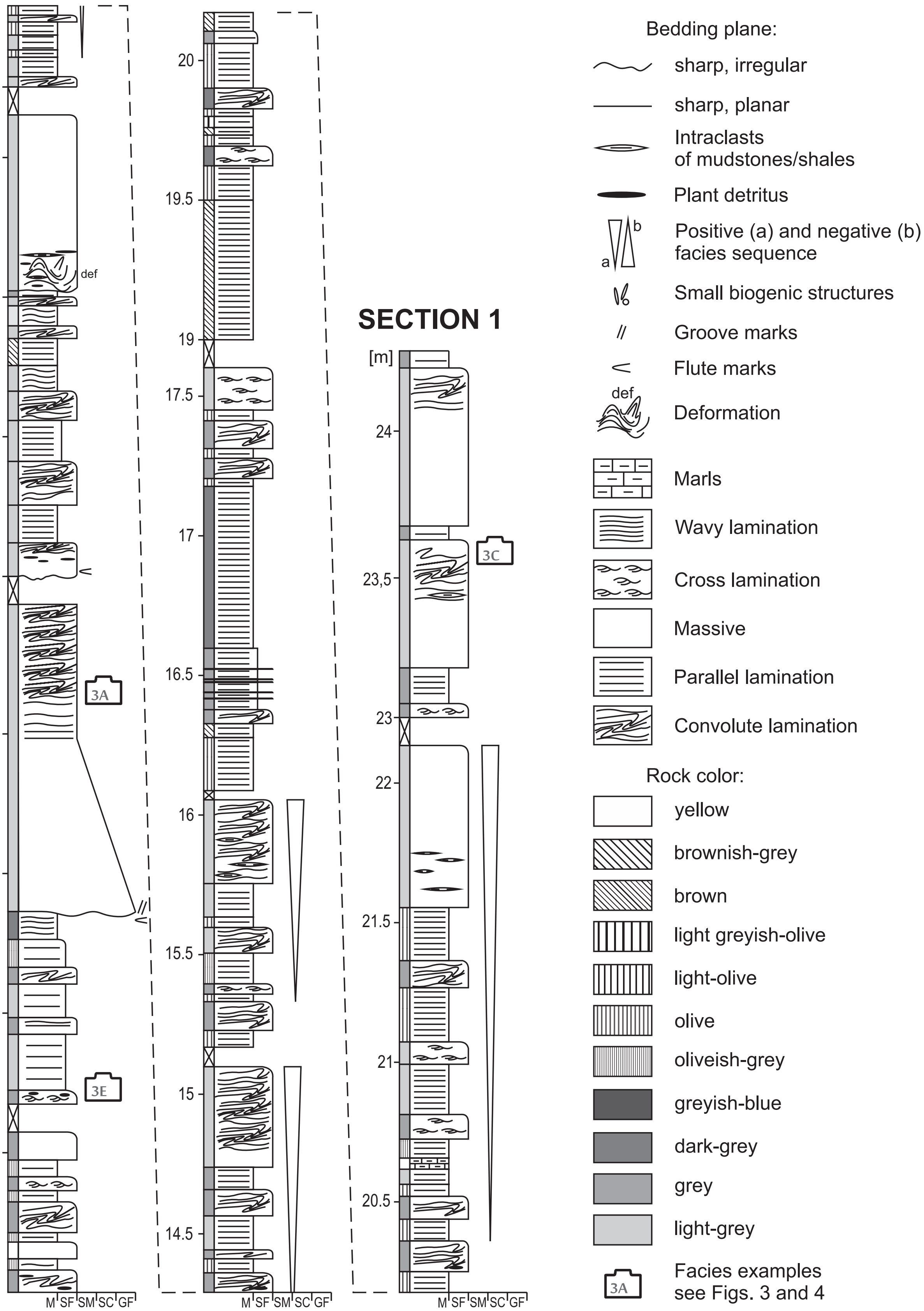
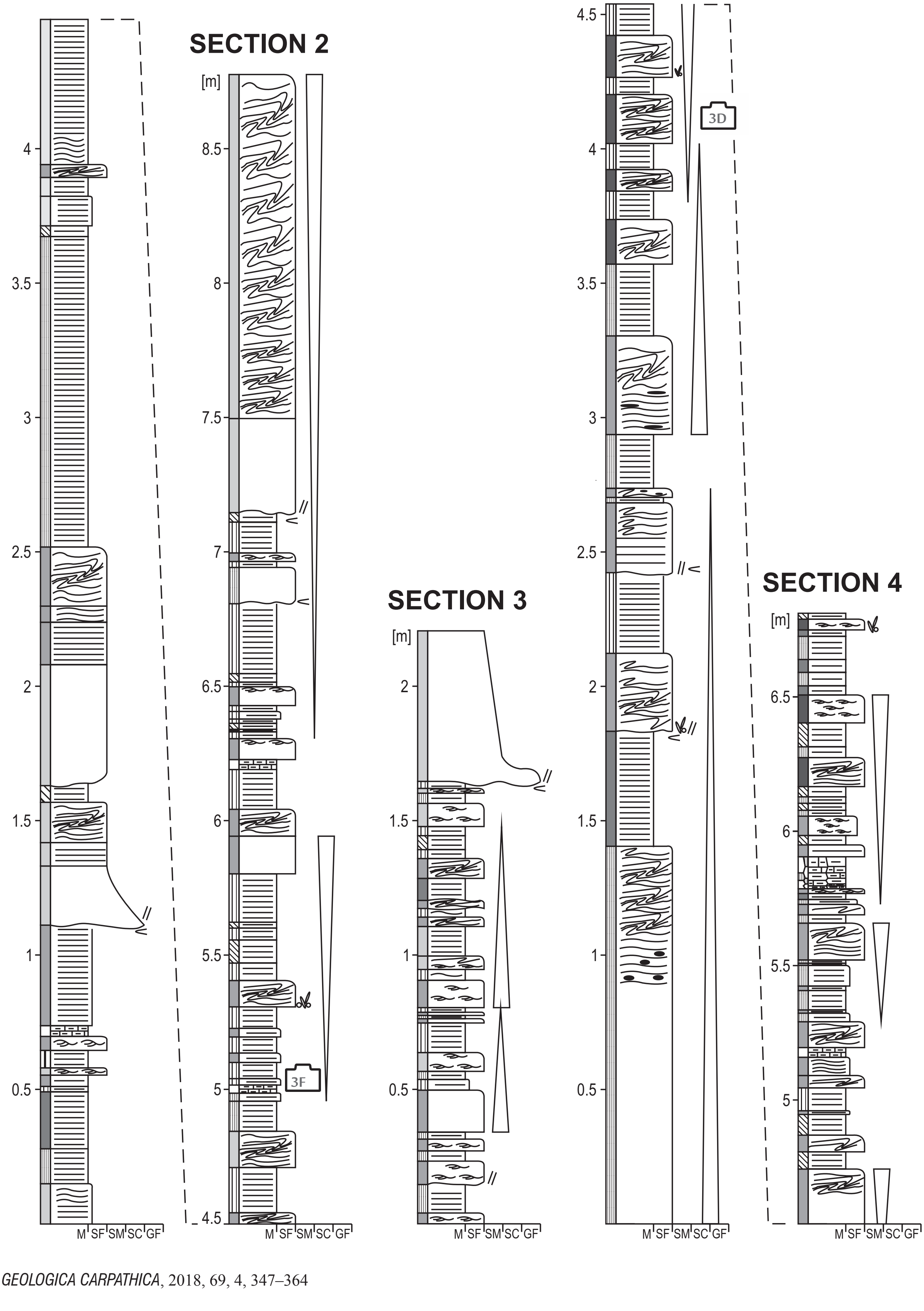
Supplement

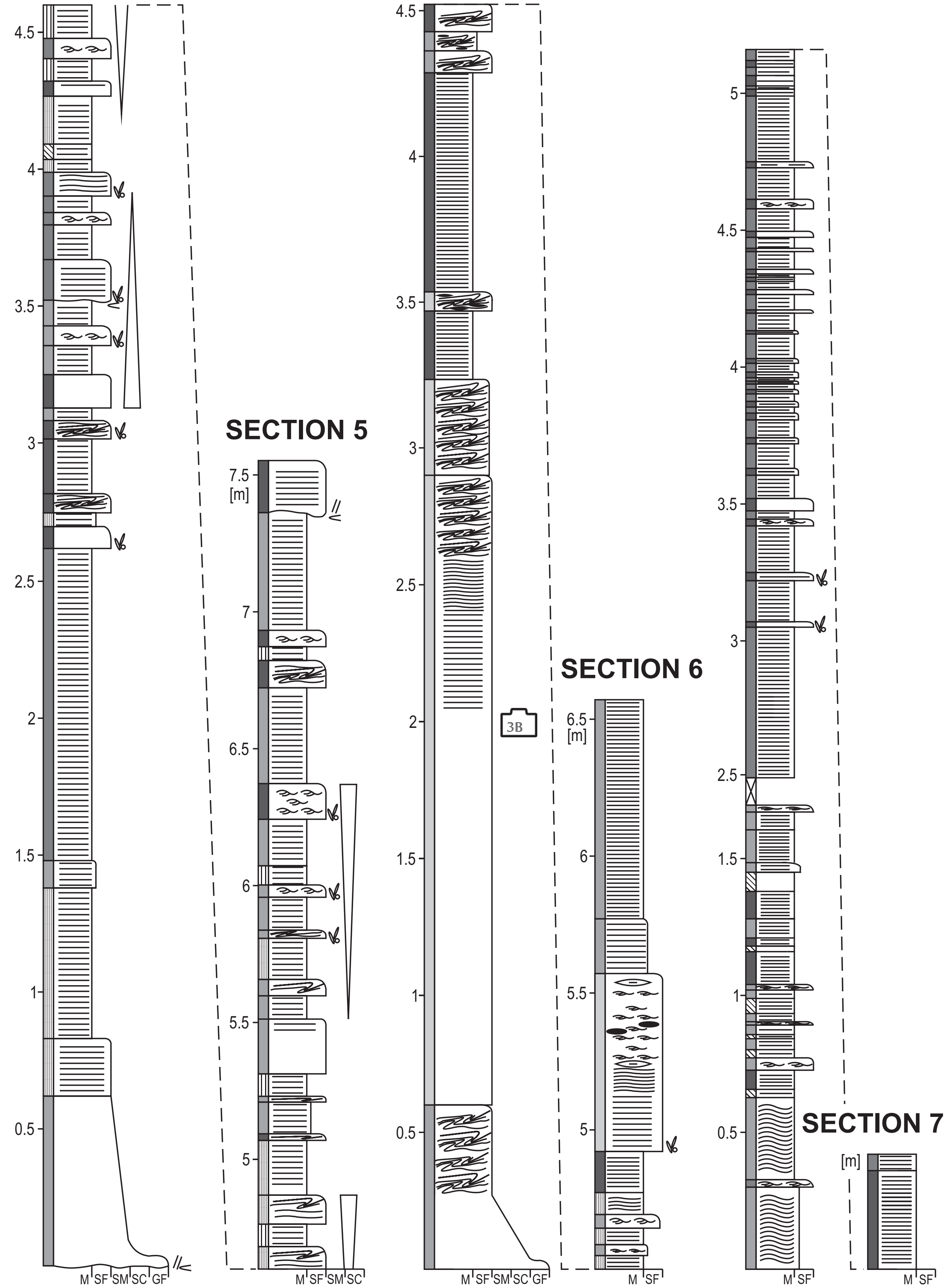
Appendix 1: Detailed sedimentological sections of the Zembrzyce Beds (see Appendix 2).



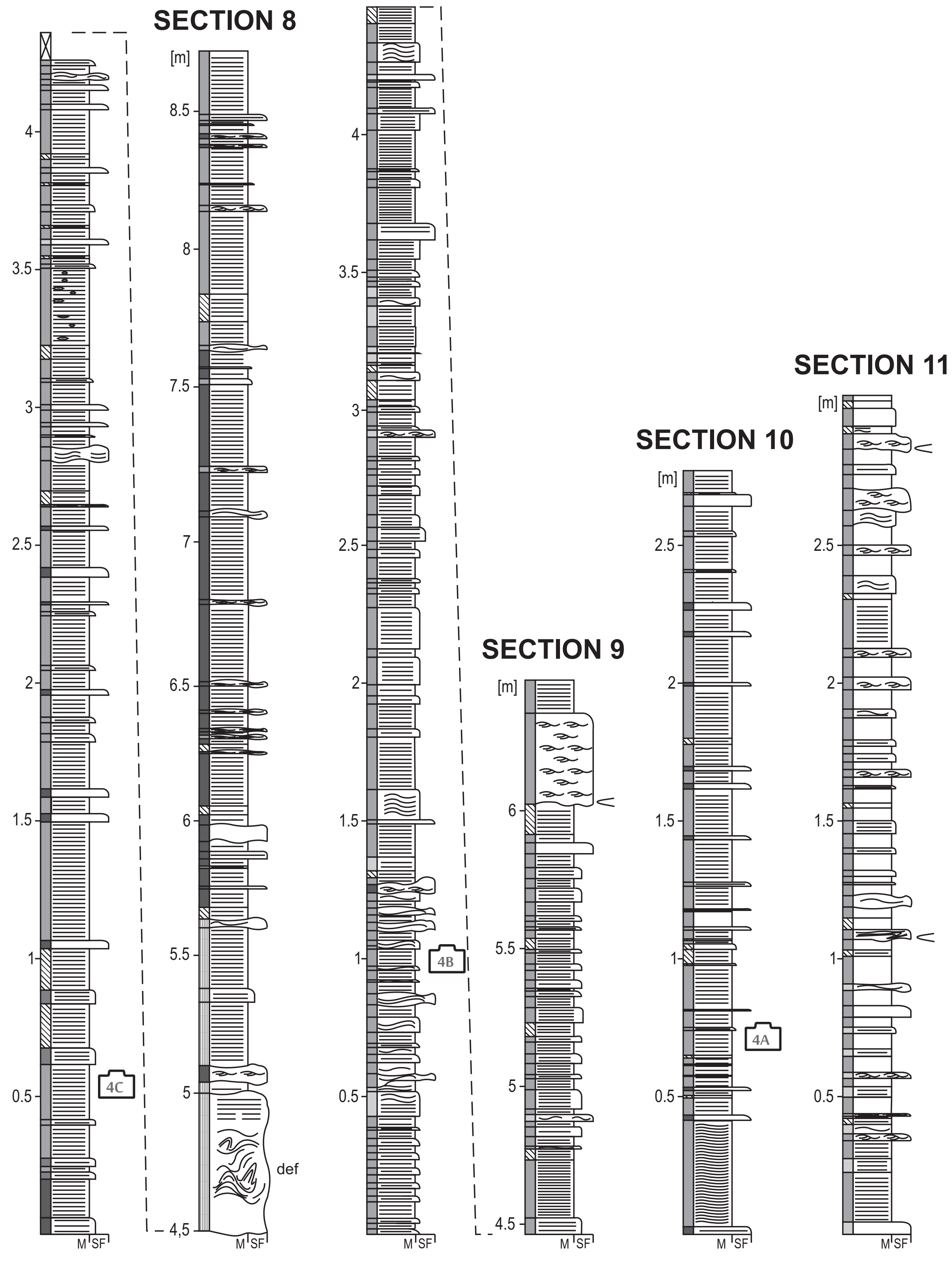
Appendix 1 (continued)



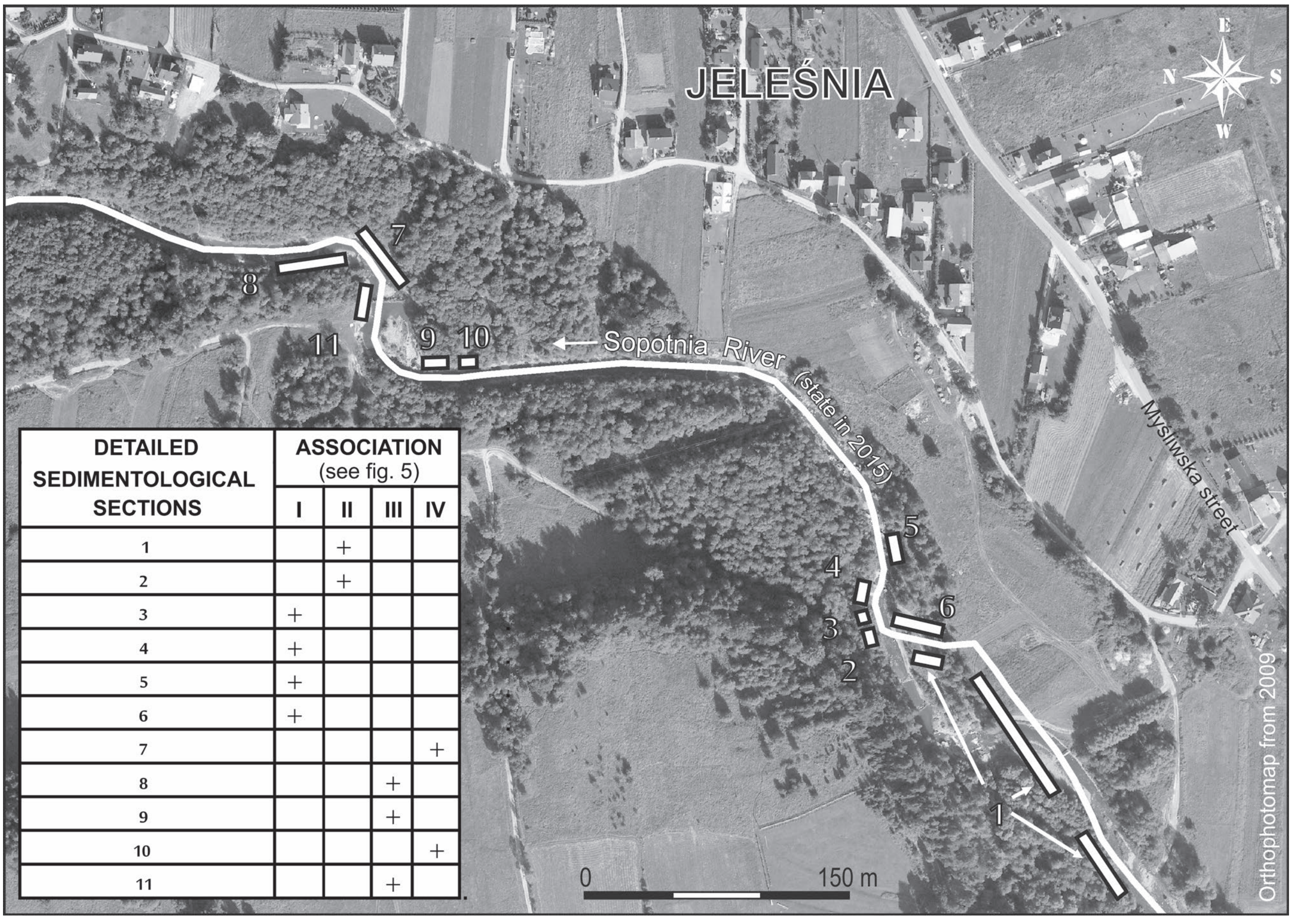
Appendix 1 (continued)



Appendix 1 (continued)



Appendix 2: Location of the detailed sedimentlogical sections and facies associations in the study area (source Orthophotomap 2009: License No. DIO.DFT.DSI.7211.18428.2014_PL_N for the University of Silesia in Katowice).



DETAILED SEDIMENTOLOGICAL SECTIONS	ASSOCIATION (see fig. 5)			
	I	II	III	IV
1		+		
2		+		
3	+			
4	+			
5	+			
6	+			
7				+
8			+	
9			+	
10				+
11			+	